Measurement and Analyses of Force Plate Accuracy and Noise for a Computer Assisted Rehabilitation Environment (CAREN)

Brian Anderson, BSE
Pinata Sessoms, PhD

Naval Health Research Center

Report No. 13-57 supported by the Defense Health Program (6.7 Funding) under Work Unit No. 61030.

Naval Health Research Center
140 Sylvester Road
San Diego, CA 92106-3521

Measurement and Analyses of Force Plate Accuracy and Noise for a Computer Assisted Rehabilitation Environment (CAREN)

Brian Anderson, BSE, and Pinata Sessoms, PhD
Naval Health Research Center

Summary

Naval Health Research Center (NHRC) in San Diego houses a Computer Assisted Rehabilitation Environment (CAREN) used for rehabilitation and research of the Warfighter. The CAREN system, equipped with a Forcelink treadmill and force plates, experiences variable force plate noise that can change between days and with a slight dependence on the weight placed on the device. The noise affects various applications and prevents consistent controls and accurate data recording. In order to understand the effect that noise has on the system and in CAREN applications, various weights were placed on the platform in multiple 3-second-long trials. The resulting force, center of pressure (CoP), and marker data were compared across several weights over multiple days. These data were also compared with another CAREN located at Walter Reed National Military Medical Center (WRNMMC) and with standard in-ground AMTI force plates at Naval Medical Center San Diego (NMCSD) to determine if the noise has only a local effect on the NHRC CAREN. It was determined that the NHRC CAREN and the WRNMMC CAREN experience the same amount of noise, which is much higher than the noise experienced by standard in-ground AMTI force plates such as those at NMCSD. It is recommended that all force and CoP data used by CAREN applications be first run through a filter before being used in a task, and that using low-force recordings be used cautiously or avoided entirely.

Introduction

The Computer Assisted Rehabilitation Environment (CAREN; Motek Medical BV, Amsterdam, The Netherlands) located at Naval Health Research Center (NHRC) is an immersive virtual environment and motion analysis laboratory designed for interactive rehabilitation and research of human performance. The CAREN has a 9-foot-diameter motion base that can move with 6 degrees of freedom and is equipped with a dual-belt (side-by-side) treadmill (Forcelink BV, Culemborg, The Netherlands) with instrumented Forcelink force plates (one under each belt) integrated into the moveable platform (Figure 1). This treadmill was labeled as a second-generation Forcelink treadmill by Motek Medical and was one of the first split-belt treadmills installed for a CAREN. The force plates measure the ground reaction forces (GRFs) and moments in the x, y, and z axes due to the subject's movements on the plates. The signals from the force transducers within the force plates are brought in as raw data and imported as analog inputs within the motion capture software (Motion Analysis Corp., Santa Rosa, CA) where a conversion matrix is used to calculate forces and moments. Center of pressure (CoP), or the point of application on the plate of the GRF vector, can also be calculated. These data can be synchronized with the motion capture marker data within the motion capture software, both of which can be used as controls for various functions within CAREN applications, such as activating certain events or acting as a biofeedback device to control objects within the virtual environment. However, the force plates have difficulty recording instantaneous GRF measurements and low-weight CoP measurements accurately due to high levels of noise within the signal. If an application requires a force threshold to be met on foot strike for some kind of event, the noise can cause the threshold to be met too early or too late in the step, preventing consistent control timings. Furthermore, if the force signal is used to control the motion of the platform, such as the roll of the platform following a weight shift, the noise can be large enough to cause small oscillations in the CAREN platform's movement. Therefore, a complete understanding of the level of noise is required to create well-functioning control systems and to accurately process and use force data for

Figure 1. The Computer Assisted Rehabilitation Environment (CAREN) at NHRC. The force plates are integrated with the dual-belt treadmill (bordered in red).

biomechanical analyses. The purpose of this paper is to quantify the force plate signal noise in NHRC's CAREN system and to compare the level of noise it experiences with that experienced by other sites.

Method

Calibration weights

To examine the noise on the force plates, a custom point mass stand was constructed so that various weights could be tested in addition to a calibration weight supplied by Motek Medical. The stand was built using two 3-inch-long bolts, three hex nuts, two washers, and a small wooden platform, with a retroreflective marker placed on top of the stand to acquire a 3D position utilizing the motion capture system (Figure 2). Olympic weight plates were centered on the stand so that it balanced on the hex nut at the end of the stand. The bottom face of the hex nut at the bottom of the stand—which served as the base on which the point mass balanced—had a diameter of 2 cm, whereas the base of the calibration weight supplied by Motek Medical had a 3.5-cm diameter. This reduced the area from 38.48 cm^2 for the Motek Medical calibration weight to 12.57 cm^2 for the NHRC custom calibration stand in an attempt to reduce any offset on CoP that could be caused by nonuniform weight distribution. In order to record the CoP error, the marker on the top of the stand allowed for 12 Raptor-E motion capture cameras (Motion Analysis Corp., Santa Rosa, CA) to record its position on the platform. Placement of the marker was such that it was vertically aligned with the position of the bottom washer. To establish CoP error, the marker's position and the CoP location given by the force plates could then be compared. The vertical height of the marker on the point mass stand was reduced from 44 cm for Motek's weight to 17.5 cm to attempt to reduce any offset between CoP and marker position that could be caused by a tilt of the stand (Figure 3).

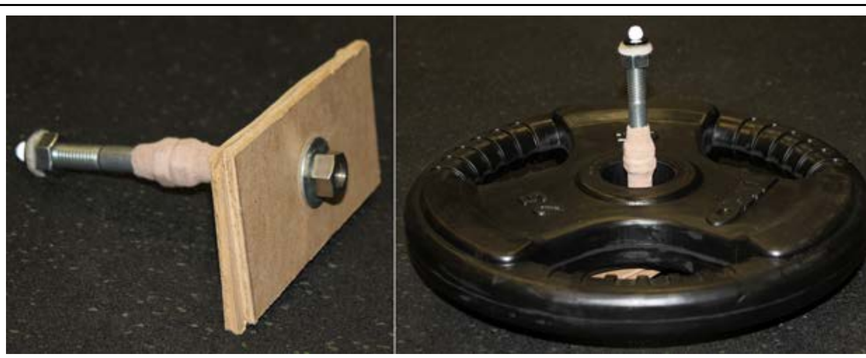

Figure 2. Pictured to the left is the custom point mass stand. The wooden platform was held in place by the washers and two hex nuts. The small area of the hex nut made it so that the weight had to be centered to balance upright (pictured right). The marker was placed on the third nut at the top of the device to allow the cameras to record its position so that it could be compared with the center of pressure given by the force plates.

Each weight was measured on a Health o meter® professional 498KL digital scale (Sunbeam Products Inc., Boca Raton, FL) to establish its actual weight. The Motek Medical calibration weight measured 31.9 kg (312.9 N), whereas the weights tested using the custom stand, including the weight of the stand, were 2.5 kg (24.5 N), 11.4 kg (111.8 N), and 20.5 kg (201.1 N). Once a particular weight was selected and placed on the platform, a simple application in the CAREN software, D-Flow, recorded the force, the CoP, and the marker position.

Force plate measurements

Each force plate within NHRC's CAREN has six force transducers, three measuring fore-aft (z) forces, two measuring medial-lateral (x) forces, and one measuring vertical (y) force. The raw analog signal from these sensors are passed as voltages to an NI USB-6225 Multifunction DAQ module (National Instruments, Austin, TX). The DAQ functions as an A/D converter which is recognized by the motion capture software, Cortex (Motion Analysis Corp., Santa Rosa, CA), used at NHRC. Cortex converts the analog signals from the force plates into GRFs and moments using a known calibration matrix. Cortex calculates and records 3D marker positions (mocap data) in synch with the analog data. Once the forces, CoP, and marker position are calculated by Cortex, it is sent to D-Flow in real time, and these data are recorded within the D-Flow software at an approximately 300-Hz sampling rate for 3 seconds. For this study, marker data were collected within Cortex at 120 Hz and forces at 1200 Hz, so marker data are repeated for certain frames and some analog data not recorded within D-Flow. The recording frame rate is not consistent within D-Flow. The force axes were defined along the platform as Y being vertical, X being lateral across the platform, and Z being longitudinal in the direction of motion of the treadmill belt. The origin of the three axes was located at the center of the platform, with a

Figure 3. Motek's calibration weight (top) and the custom point mass stand without the wooden platform for the Olympic weights (bottom).

force plate on either side of the X axis; left plate represented the negative X plane, and right plate represented the positive X plane. Both the CoP and marker position were defined with an X and Z location on the plane of the treadmill.

The effect of filtering was analyzed by collecting three types of data: (1) unfiltered data directly from Cortex, (2) data passed through a 10-Hz second-order Butterworth low-pass filter, and (3) data passed through a 6-Hz second-order Butterworth low-pass filter. Initial force plate measurements were taken on 13 August 2012 using Motek's calibration weight of 31.9 kg (Test Group 1 in Table 1). Ten trials (3 seconds in length per trial) in 10 random positions (5 for the left and 5 for the right) were obtained, and data for each filter type were recorded to a file using D-Flow's Record Data module.

Day-to-day repeatability was also tested by recording data using the 11.4-kg weight on the NHRC CAREN on 2 separate days (21 August 2012 and 22 August 2012). A total of 15 trials were recorded on the first day, and six trials were recorded on the second. On 21 August 2012, the 11.4-kg weight was tested on the left force plate for 10 trials and on the right force plate for 5 trials. The reason for taking 10 trials on the left force plate was because it was believed the first 5 trials were taken incorrectly. After the data were examined it was determined that the trials were taken correctly, so all data were used in the analyses. On 22 August 2012, the 2.5-kg and 20.5-kg weights were also tested on the CAREN to look at potential differences in force plate measurement due to calibration weight differences. Trials for each weight were collected in quick succession so that the force plates had the same initial conditions such as prior usage that day and temperature of the room. Changes in recordings were expected to be from the sensors and weights and not other factors. The 2.5-kg and the 20.5-kg weight were each tested 10 times, 5 positions on the left plate and 5 on the right, and the 11.4-kg weight was tested 3 times on each plate. The locations of the weights on the force plates were chosen at random but were either completely on the left plate or right plate so that no force was distributed across both plates. Table 1 lists the different recordings made on each day and at each site.

Data were taken using a similar method at Naval Medical Center San Diego (NMCSD) on one of several in-ground mounted OR6-7-1000 AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA) with the same NHRC custom point mass stand and set of weights (Test Group 5 in Table 1). The stand and one of the weights were placed on a force plate so that the vertical force, the CoP position, and the marker position could be recorded with an 1800-Hz sampling rate for 3 seconds. Five trials each were recorded for 2.5-kg, 11.4-kg, and 20.5-kg weights on NMCSD's force plates on 23 August 2012 in quick succession to keep the same initial conditions.

Walter Reed National Military Medical Center (WRNMMC) staff used the same method to record on their CAREN but only used the calibration weight provided by Motek Medical,

weighing approximately 32.6 kg (320 N) by WRNMMC measurement (Test Group 6 in Table 1). WRNMMC staff recorded 15 trials on their left plate and 4 on the right, but only reported trials taken with a 10-Hz filter. These data were compared with NHRC's measurements taken on 13 August 2012 (Test Group 1) with the same approximate weight (31.9 kg) described previously.

Data processing

Once data were recorded, they were run through a MATLAB (Mathworks, Natick, MA) script (Appendix A) that opened a matrix containing a list of all the trials taken on the same day and with the same weight. The script then computed the maximum error, noise range, and offset (average) of each trial and saved that information to a new matrix. It computed the CoP error by subtracting the measured marker location from the CoP location, the force error by subtracting the expected force (mass of calibration weight) from the recorded vertical ground reaction force, and the range by subtracting the lowest measured value from the highest measured value over each 3-second trial. When the script finished processing all the files in the list, it then computed the average of the offsets, maximum errors, and ranges as well as their standard deviations.

Results and Discussion

For these analyses the left and right force plates are not differentiated from one another. Since both force plates are used in a typical CAREN application, noise on either plate will affect the accuracy of the biomechanical analysis. Therefore, combining the results of both plates helps to understand the total effect that the noise would have on the data. Additionally, it allows different types of force plates to be compared. Offsets in the average force could have occurred because of minor differences in the mechanics of the force plates and the scale used to establish the weight, thus maximum errors are taken to be the point furthest away from the mean of a particular 3-second recording. Since this report is more concerned with the noise in the system,

Table 1. Trial List of Force Plate Recordings Taken at Different Testing Sites and Days

Test Group (Appendix)	**Site**	**Date**	**Number of Trials per Weight**	**Weight Tested (kg)**	**Filters Used (Hz)**
1 (D)	NHRC	13 Aug 2012	10	31.9	0, 6, 10
2 (C)	NHRC	21 Aug 2012	15	11.4	0, 6, 10
3 (B)	NHRC	22 Aug 2012	10	2.5, 20.5	0, 6, 10
4 (B)	NHRC	22 Aug 2012	6	11.4	0, 6, 10
5 (E)	NMCSD	27 Aug 2012	5	2.5, 11.4, 20.5	0
6 (F)	WRNMMC	27 Sep 2012	19	32.6	10

rather than the mechanical differences of the plates, offsets were mostly ignored. However, each force plate does have a slightly different force offset, therefore, sets of data containing more trials on one plate than the other would mean that the average offset might bias toward the value of the plate with more trials. In our trials, this does not prevent accurate comparisons between trials since the difference between plates was never measured to be more than 2 N, which is smaller than the standard deviations for expected force seen in several trials. Offsets for the CoP error could have been caused by a tilt in the stand in addition to the noise and thus are also ignored.

Comparison of NHRC CAREN Same Weight Tests Between Days (Test Groups 2 and 4)

The 11.4-kg weight tested on the NHRC CAREN showed a large variability in the noise between the 2 separate days of recording. When comparing the data for the 11.4-kg weight on the second day (Test Group 4, Appendix B) with that for the first day (Test Group 2, Appendix C), the maximum error in marker position and force doubled, even when filtered. The standard deviation for the maximum error of marker position and force in the Z axis had very minor differences, nearly doubled in the X axis, and more than doubled in the Y axis. The range of the noise also nearly doubled for all marker and force recordings. There was little difference in standard deviations for marker position and force in the Z axis but it more than doubled for the force in the X and Y axes. Although the increase in the standard deviations for the trials taken the second day (Test Group 4) may have been a result of the reduced number of trials, the increase shows that at least some trials in Test Group 4 had errors that were much greater than those in Test Group 2. The large variability between maximum error and the range of the noise show that there is a day-to-day variance level of noise even when the same weight is used.

Comparison of NHRC CAREN Same-Day Weight Measurements (Test Groups 3 and 4)

For the trials recorded in the same day (Test Groups 3 and 4, Appendix B), the 2.5-kg, 11.4-kg, and 20.5-kg weights showed similar overall averages for the expected weight offsets. This means that when trials are taken in a short period of time the effect that noise has on the system is consistent in regard to recording forces. A different noise would result in differing offsets, as in the case of Test Group 2 vs. Test Group 4 (same weights measured on different days). However, the maximum error and noise range for the CoP error of the 2.5-kg weight was 10 times greater than that of the 20.5-kg weight. The CoP error and range for the 11.4-kg weight was only 1.5 times higher than the error for the 20.5-kg weight. This means that when a heavier weight is placed on the platform the CoP becomes more accurate but that there are diminishing returns on the benefit of increasing the total weight. Noise range and maximum error for the force recordings for the 11.4 kg and the 20.5 kg were similar to one another and were both less than the 2.5-kg test. Thus, it must be noted that the force plates are less accurate for low weights, which should come into consideration if small forces are going to be measured or used within CAREN applications. Despite the increase in accuracy with higher weights, the daily changes in the CAREN have a much larger effect on the noise. For example, the range of noise and

maximum errors for trials taken with Motek's 31.9-kg calibration weight (Test Group 1, Appendix D), are much larger than that of the 20.5-kg weight trials (Test Group 3, Appendix B).

Comparison Between NHRC CAREN Forcelink Force Plates and NMCSD AMTI Force Plates (Test Groups 2, 3, and 5)

The AMTI force plate trials (Test Group 5, Appendix E) show that there is minor weight-dependence on in-ground force plates. Although the CoP error for the 2.5-kg weight is 10 times greater than the 20.5-kg weight on the AMTI force plates, the 2.5-kg weight on the AMTI force plates was still much more accurate than the 20.5-kg weight on the NHRC CAREN (Appendix B). The range of noise and maximum error for force recording were very similar for all trials on the AMTI force plates and were minor in comparison with the total force. This means the AMTI force plates have minute weight dependence when recording the ground reaction forces. Therefore, in-ground AMTI force plates experience little error from noise and are able to more accurately record both CoP and GRF data, even when unfiltered (within the analysis software) and compared with CAREN force plates.

Comparison Between NHRC and WRNMMC CAREN Site Force Plates (Test Groups 1, 3, and 6)

The trials taken on the WRNMMC CAREN (Test Group 6, Appendix F) seem to have better force measurements than the NHRC CAREN (Test Group 1, Appendix D). The average maximum error and the noise range for the WRNMMC CAREN are lower for both CoP and force data (Table 2). When comparing forces for the 20.5-kg weight used with Test Group 3 (Appendix B), the WRNMMC CAREN measurements were not as accurate as the NHRC CAREN. The WRNMMC CAREN has smaller maximum error and smaller noise range, but the higher standard deviation means that noise would sometimes have a larger effect on the WRNMMC CAREN than it had on the NHRC CAREN. However, CoP for the WRNMMC CAREN is marginally more accurate than the 20.5-kg trials on the NHRC CAREN, which is possibly a result of the higher weight placed on the platform. Since the WRNMMC only reported 1 day of recording the performance across multiple days is unknown. Yet, because one set of trials on the NHRC CAREN was more accurate than for the WRNMMC CAREN and one set of trials was less accurate, it is likely both CARENs experience the same level of noise. Both CARENs also experience much greater error in the forces and CoP than the AMTI in-ground force plates. This means that the noise experienced by both CARENs is likely a result of the equipment used to operate the CAREN (e.g., instrumented treadmill system on a motion platform), rather than an isolated issue with the force plates at NHRC.

Table 2. Difference in Maximum Errors and Noise Range Measurements Taken on CAREN Force Plates Between NHRC and WRNMMC Sites

Measurement	NHRC Max Error – WRNMMC Max Error	NHRC Noise Range – WRNMMC Noise Range
CoPX vs. MarkerX (m)	0.0014	0.0023
CoPZ vs. MarkerZ (m)	0.0029	0.0057
ForX (N)	2.8185	4.7265
ForY – weight (N)	3.611	6.0861
ForZ (N)	1.3986	2.344

Note: NHRC values were higher for all measurements shown here.

Application for Measuring Force Plate Noise on the CAREN

Motek Medical provides a performance report that examines only the average and standard deviation of an unfiltered trial of data collected within D-Flow. Spikes in the force plate signal due to noise usually have a much larger impact than what Motek Medical's report states and can lead to such things as activating an event within D-Flow at the wrong time if the trigger is based on the force plate signal. This means that all tests that examine the noise affecting the performance of the force plates should also examine the *maximum* error and the *range* of noise. The average and standard deviation of force plate noise are necessary but not sufficient to get a full understanding of the force plate's performance. In order to help other CAREN sites analyze the noise on their force plates, NHRC has developed an application (Figure 4) that records, processes, and displays the errors in the force plate signal. The application allows the operator to select which plate to test, the number of trials to record for averaging purposes, and the expected force of the weight. The operator would then place a weight on the force plate selected and click the "Record" button. Further, the operator could then move the weight to a different location on the force plate and take a recording or simply record another trial in the same position. After recording a number of trials specified by the operator, the program calculates the data before saving and displaying it. This programming feature allows the operator to get a proper understanding of the noise affecting the system so it can be properly accounted for during D-Flow applications.

Conclusions

The NHRC CAREN is subjected to various changes between different days in the level of noise it experiences from minor shift in weight to large errors. Although the effect of the noise can be mitigated slightly by recording with higher weights, **we recommend using at least a 10-Hz low-pass filter** for any function that is going to use a weight threshold in order to reduce the

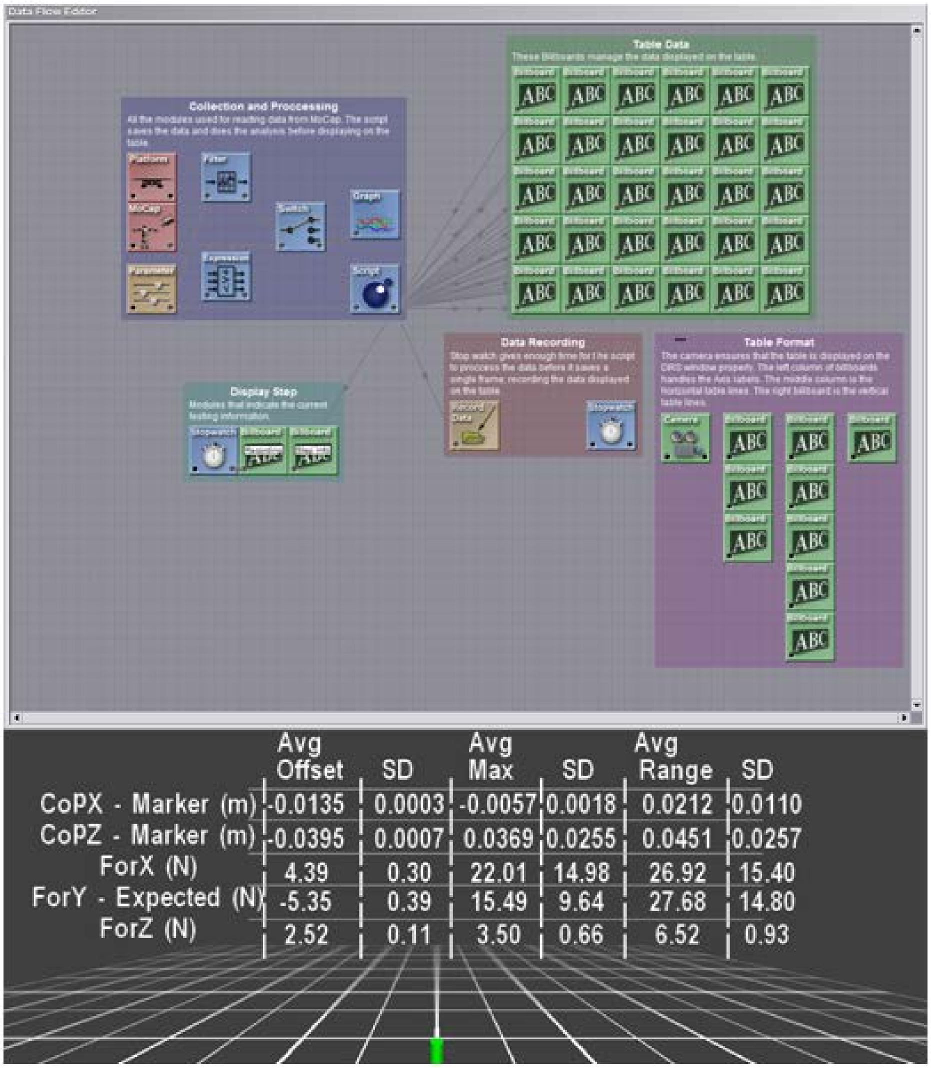

Figure 4. Top: Screenshot of the D-Flow editing screen for the application made by NHRC that shows the different modules that record, process, and display the data from the force plates (imported into D-Flow using the mocap module). Bottom: A sample output of the application with the 31.9-kg calibration weight run for 10 trials with a 10-Hz low-pass filter on the left force plate. The D-Flow application writes this information to a file that can then be used to compare measurements of varying weights, over different days, or between systems.

noise range. The CAREN at WRNMMC was affected by noise slightly more than the NHRC CAREN for one set of the high-weight trials. However, the WRNMMC CAREN performed more accurately than the NHRC CAREN when equivalent weights were used. Since the daily changes for the WRNMMC CAREN are unknown, it is just as likely that its day-to-day noise is similar to that of the NHRC CAREN. However, neither CAREN should use triggers that have a threshold < 25 N because of the weight dependence and variance in the noise, even if the data are filtered. If the recorded force on the platform is < 100 N, then the CoP should be considered inaccurate. In-ground AMTI force plates experience little error from noise and can even be operated accurately under low-weight conditions.

Taken together, the large amount of noise experienced by the NHRC CAREN is likely a result of the equipment used to operate the CAREN and type of force plate system (i.e., force plates mounted in a motion platform) since both CARENs appear to have similar noise results. Additionally, the data show that, despite the large amount of noise, the CAREN is able to accurately measure force if the average force can be used, as seen by the relatively low offsets when compared with the noise ranges. However, if a real-time force measurement is required, it should be filtered within D-Flow. Force plate noise must be taken into account when using the force signal within a D-Flow application. Therefore, each CAREN should run tests similar to that provided in this report to determine if the noise range is at an acceptable level.

Appendix A: MATLAB Code for Analyzing Force Plate Data

```
%This plots all the trials and computes the overall average, average of
%maximums and the standard deviations of the two CAREN force plates.

clear all;
[filename, pathname, ~] = uigetfile('.mat');
[~, filelocation, ~] = uigetfile('.txt');
addpath(pathname);
addpath(filelocation);
load(filename);
counter = 1;

%Opens the report file and cycles through all the listed files
for n = 1:size(Report_File_List,1);
    File_Name = Report_File_List{n};
    Raw = struct2cell(importdata([File_Name '.txt']));
    Raw_Trial_Data = Raw{3};
    Raw_Trial_Data(2:size(Raw{1},1)+1, 1:23) = num2cell(Raw{1});
    %If there is no weight then it makes sure the data are listed with 0 in
    %expected force.
    if any(strfind(char(File_Name), 'NoW'))
        for i = 2:(size(Raw{1},1)+1);
            Raw_Trial_Data{i,23} = 0;
        end
    end

    %If the report is listed as the left platform then we compare CoP to
    %the marker data starting with column 5, else assume it's right
    %plate and start comparing data at column 10
    if Report_File_List{n,2} == 'L'
        position = 5;
    else
        position = 10;
    end

    %Takes the raw file and reorganizes it into a matrix that is going to
    %be used to pull data from
    Trial_Data = cell(size(Raw_Trial_Data,1),15);
    Trial_Data(1,1) = Raw_Trial_Data(1,1);
    Trial_Data(:,2:15) = Raw_Trial_Data(:,[2 3 4 5 7 8 9 10 14 16 17 18 19 23]);
    for i = 2:size(Raw_Trial_Data,1)
        Trial_Data{i,1} = Raw_Trial_Data{i,1} - Raw_Trial_Data{2,1};
```

```
    end

    %plots all of the raw data in the files with the mean line and two
    %deviation lines
    figure
    Time = cell2mat(Trial_Data(2:end,1));
    CopXvMarkerX = cell2mat( Trial_Data(2:end,position))- cell2mat( Trial_Data(2:end,2) );
    CopZvMarkerZ = cell2mat( Trial_Data(2:end,position+1)) - cell2mat(Trial_Data(2:end,4));
    ForceXdiff = cell2mat(Trial_Data(2:end,position + 2));
    ForceYdiff = cell2mat(Trial_Data(2:end,position + 3)) - cell2mat(Trial_Data(2:end,15));
    ForceZdiff = cell2mat(Trial_Data(2:end,position + 4));
    subplot(3,2,1); plot(Time,CopXvMarkerX);
    line([0 3], [mean(CopXvMarkerX) mean(CopXvMarkerX)],  'Color', 'r', 'LineStyle', '--');
    line([0 3], [mean(CopXvMarkerX)- std(CopXvMarkerX) mean(CopXvMarkerX) -
std(CopXvMarkerX)],  'Color', 'k', 'LineStyle', '--');
    line([0 3], [(mean(CopXvMarkerX)+ std(CopXvMarkerX)) (mean(CopXvMarkerX) +
std(CopXvMarkerX))],  'Color', 'k', 'LineStyle', '--');
    title('CopX - MarkerX (m)');
    subplot(3,2,2); plot(Time,CopZvMarkerZ);
    line([0 3], [mean(CopZvMarkerZ) mean(CopZvMarkerZ)],  'Color', 'r', 'LineStyle', '--');
    line([0 3], [mean(CopZvMarkerZ)- std(CopZvMarkerZ) mean(CopZvMarkerZ) -
std(CopZvMarkerZ)],  'Color', 'k', 'LineStyle', '--');
    line([0 3], [(mean(CopZvMarkerZ)+ std(CopZvMarkerZ)) (mean(CopZvMarkerZ) +
std(CopZvMarkerZ))],  'Color', 'k', 'LineStyle', '--');
    title('CopZ - MarkerZ (m)');
    subplot(3,2,3); plot(Time,ForceXdiff);
    line([0 3], [mean(ForceXdiff) mean(ForceXdiff)],  'Color', 'r', 'LineStyle', '--');
    line([0 3], [mean(ForceXdiff)- std(ForceXdiff) mean(ForceXdiff) - std(ForceXdiff)],  'Color',
'k', 'LineStyle', '--');
    line([0 3], [(mean(ForceXdiff)+ std(ForceXdiff)) (mean(ForceXdiff) + std(ForceXdiff))],
'Color', 'k', 'LineStyle', '--');
    title('ForX (N)');
    subplot(3,2,4); plot(Time,ForceYdiff);
    line([0 3], [mean(ForceYdiff) mean(ForceYdiff)],  'Color', 'r', 'LineStyle', '--');
    line([0 3], [mean(ForceYdiff)- std(ForceYdiff) mean(ForceYdiff) - std(ForceYdiff)],  'Color',
'k', 'LineStyle', '--');
    line([0 3], [(mean(ForceYdiff)+ std(ForceYdiff)) (mean(ForceYdiff) + std(ForceYdiff))],
'Color', 'k', 'LineStyle', '--');
    title('ForY - expected (N)');
    subplot(3,2,6); plot(Time, ForceZdiff);
    line([0 3], [mean(ForceZdiff) mean(ForceZdiff)],  'Color', 'r', 'LineStyle', '--');
    line([0 3], [mean(ForceZdiff)- std(ForceZdiff) mean(ForceZdiff) - std(ForceZdiff)],  'Color',
'k', 'LineStyle', '--');
```

```
    line([0 3], [(mean(ForceZdiff)+ std(ForceZdiff)) (mean(ForceZdiff) + std(ForceZdiff))], 'Color', 'k', 'LineStyle', '--');
    title('ForZ (N)');

    %Builds the table that is on the plot
    ColNames = cell(1,4);
    ColNames{1,1} = 'Mean';
    ColNames{1,2} = 'STDD';
    ColNames{1,3} = 'Max from mean';
    ColNames{1,4} = 'Range';
    RowNames = cell(5,1);
    RowNames{1,1} = 'CopXvMarkerX (m)';
    RowNames{2,1} = 'CopZvMarkerZ (m)';
    RowNames{3,1} = 'ForX - expected (N)';
    RowNames{4,1} = 'ForY - expected (N)';
    RowNames{5,1} = 'ForZ - expected (N)';
    %Stores all the data from a trial into the table on the plot
    Data(1,1) = mean(CopXvMarkerX);
    Data(1,2) = std(CopXvMarkerX);
    Data(1,3) = max(abs(CopXvMarkerX - mean(CopXvMarkerX)));
    Data(1,4) = max(CopXvMarkerX) - min(CopXvMarkerX);
    Data(2,1) = mean(CopZvMarkerZ);
    Data(2,2) = std(CopZvMarkerZ);
    Data(2,3) = max(abs(CopZvMarkerZ - mean(CopZvMarkerZ)));
    Data(2,4) = max(CopZvMarkerZ) - min(CopZvMarkerZ);
    Data(3,1) = mean(ForceXdiff);
    Data(3,2) = std(ForceXdiff);
    Data(3,3) = max(abs(ForceXdiff - mean(ForceXdiff)));
    Data(3,4) = max(ForceXdiff) - min(ForceXdiff);
    Data(4,1) = mean(ForceYdiff);
    Data(4,2) = std(ForceYdiff);
    Data(4,3) = max(abs(ForceYdiff - mean(ForceYdiff)));
    Data(4,4) = max(ForceYdiff) - min(ForceYdiff);
    Data(5,1) = mean(ForceZdiff);
    Data(5,2) = std(ForceZdiff);
    Data(5,3) = max(abs(ForceZdiff - mean(ForceZdiff)));
    Data(5,4) = max(ForceZdiff) - min(ForceZdiff);
    uitable('Data', Data, 'ColumnName', ColNames, 'RowName', RowNames, 'Position', [200 100 600 200]);
    [ax4, h3] = suplabel(File_Name, 't');
```

```
    set(h3, 'FontSize', 16);

    %Once the data are collected it builds a new temporary matrix and
    %appends the new information from the current file that is open. When
    %it cycles through all the files in the file list these temporary
    %matrixs expand accordingly. Excludes any no weight trials
    if any(strfind(char(File_Name), 'NoW')) ~= 1;
        Temp_Overall_CopX(counter) = mean(CopXvMarkerX);
        Temp_Overall_CopZ(counter) = mean(CopZvMarkerZ);
        Temp_Overall_ForX(counter) = mean(ForceXdiff);
        Temp_Overall_ForY(counter) = mean(ForceYdiff);
        Temp_Overall_ForZ(counter) = mean(ForceZdiff);
        Temp_Max_CopX(counter) = max(abs(CopXvMarkerX - mean(CopXvMarkerX)));
        Temp_Max_CopZ(counter) = max(abs(CopZvMarkerZ - mean(CopZvMarkerZ)));
        Temp_Max_ForX(counter) = max(abs(ForceXdiff - mean(ForceXdiff)));
        Temp_Max_ForY(counter) = max(abs(ForceYdiff - mean(ForceYdiff)));
        Temp_Max_ForZ(counter) = max(abs(ForceZdiff - mean(ForceZdiff)));
        Temp_Range_CopX(counter) = max(CopXvMarkerX) - min(CopXvMarkerX);
        Temp_Range_CopZ(counter) = max(CopZvMarkerZ) - min(CopZvMarkerZ);
        Temp_Range_ForX(counter) = max(ForceXdiff) - min(ForceXdiff);
        Temp_Range_ForY(counter) = max(ForceYdiff) - min(ForceYdiff);
        Temp_Range_ForZ(counter) = max(ForceZdiff) - min(ForceZdiff);
        counter = counter + 1;
    end
end
%Makes a table with all the data
Table = cell(6,7);
Table{1,2} = 'Overall Average';
Table{1,3} = 'Standard Deviation';
Table{1,4} = 'Average of Maximums';
Table{1,5} = 'Standard Deviation';
Table{1,6} = 'Average Range';
Table{1,7} = 'Standard Deviation';
Table{2,1} = 'CopX vs MarkerX (m)';
Table{3,1} = 'CopZ vs MarkerZ (m)';
Table{4,1} = 'ForX (N)';
Table{5,1} = 'ForY - calibration weight (N)';
Table{6,1} = 'ForZ (N)';

%Fills the table with the average offset, average max error, average noise
%range as well as their standard deviations
Table{2,2} = mean(Temp_Overall_CopX);
Table{3,2} = mean(Temp_Overall_CopZ);
Table{4,2} = mean(Temp_Overall_ForX);
```

```
Table{5,2} = mean(Temp_Overall_ForY);
Table{6,2} = mean(Temp_Overall_ForZ);
Table{2,3} = std(Temp_Overall_CopX);
Table{3,3} = std(Temp_Overall_CopZ);
Table{4,3} = std(Temp_Overall_ForX);
Table{5,3} = std(Temp_Overall_ForY);
Table{6,3} = std(Temp_Overall_ForZ);
Table{2,4} = mean(Temp_Max_CopX);
Table{3,4} = mean(Temp_Max_CopZ);
Table{4,4} = mean(Temp_Max_ForX);
Table{5,4} = mean(Temp_Max_ForY);
Table{6,4} = mean(Temp_Max_ForZ);
Table{2,5} = std(Temp_Max_CopX);
Table{3,5} = std(Temp_Max_CopZ);
Table{4,5} = std(Temp_Max_ForX);
Table{5,5} = std(Temp_Max_ForY);
Table{6,5} = std(Temp_Max_ForZ);
Table{2,6} = mean(Temp_Range_CopX);
Table{3,6} = mean(Temp_Range_CopZ);
Table{4,6} = mean(Temp_Range_ForX);
Table{5,6} = mean(Temp_Range_ForY);
Table{6,6} = mean(Temp_Range_ForZ);
Table{2,7} = std(Temp_Range_CopX);
Table{3,7} = std(Temp_Range_CopZ);
Table{4,7} = std(Temp_Range_ForX);
Table{5,7} = std(Temp_Range_ForY);
Table{6,7} = std(Temp_Range_ForZ);
```

Example of file list that would be loaded for analysis:

'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0001'	'L'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0002'	'L'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0003'	'L'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0004'	'L'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0005'	'L'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0006'	'R'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0007'	'R'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0008'	'R'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0009'	'R'
'13AUG12 Weight PlatformOn WithThreshhold 6HzFilter0010'	'R'

Appendix B: NHRC Force Plate Measurements for Groups 3 and 4

NHRC CAREN Measurements: 2.5-kg, 11.4-kg, and 20.5-kg weights filtered at 0, 6, and 10 Hz

22 Aug 2012 Data: 2.5-kg weight (24.5 N) used. Not filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	0.0039	0.0078	0.1171	0.0471	0.1909	0.0520
CoPZ vs. MarkerZ (m)	0.0294	0.0478	0.2136	0.1255	0.3519	0.1671
ForX (N)	-0.4617	1.8493	6.4574	1.2299	12.0248	1.8375
ForY – weight (N)	-0.3288	0.6702	11.5520	6.3229	19.4221	7.1991
ForZ (N)	2.3817	0.2594	4.4562	0.5040	8.4138	0.6404

22 August 2012 Data: 2.5-kg weight (24.5 N) used. 10 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	0.0038	0.0078	0.0446	0.0224	0.0756	0.0283
CoPZ vs. MarkerZ (m)	0.0293	0.0480	0.0794	0.0404	0.1318	0.0501
ForX (N)	-0.4576	1.8554	2.9983	0.5756	5.4717	0.8643
ForY – weight (N)	-0.3282	0.6959	4.5437	2.6918	7.6673	3.2642
ForZ (N)	2.3830	0.2625	1.7056	0.2598	3.1445	0.4656

22 August 2012 Data: 2.5-kg weight (24.5 N) used. 6 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	0.038	0.0077	0.0294	0.0148	0.0512	0.0205
CoPZ vs. MarkerZ (m)	0.0292	0.0480	0.0559	0.0286	0.0943	0.0355
ForX (N)	-0.4539	1.8586	2.2990	0.5934	4.2089	0.8475
ForY – weight (N)	-0.3202	0.6766	3.1481	1.5306	5.4175	2.1336
ForZ (N)	2.3835	0.2597	1.2234	0.2775	2.2202	0.4203

22 August 2012 Data: 11.4-kg weight (111.8 N) used. Not filtered. 6 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0062	0.00058	0.0173	0.0022	0.0332	0.040
CoPZ vs. MarkerZ (m)	0.0067	0.0127	0.0275	0.0029	0.0512	0.0043
ForX (N)	-0.1495	2.2148	7.5438	1.8752	13.2178	2.1843
ForY – weight (N)	0.3754	0.1994	8.5347	1.7897	15.4559	3.0933
ForZ (N)	2.4527	0.6108	4.2627	0.6677	7.9266	1.1295

22 Aug 2012 Data: 11.4-kg weight (111.8 N) used. 10 Hz filtered. 6 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0062	0.00058	0.0066	0.0011	0.0123	0.0018
CoPZ vs. MarkerZ (m)	0.0067	0.0128	0.0102	0.0012	0.0199	0.0021
ForX (N)	-0.1502	2.1290	3.0784	0.5224	5.5266	0.6169
ForY – weight (N)	0.3730	0.2010	3.2092	0.6697	5.9082	1.0686
ForZ (N)	2.4517	0.6022	1.6250	0.1956	3.0564	0.4167

22 Aug 2012 Data: 11.4-kg weight (111.8 N) used. 6 Hz filtered. 6 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0062	0.00058	0.0049	0.00082	0.0090	0.0015
CoPZ vs. MarkerZ (m)	0.0067	0.0128	0.0077	0.00075	0.0146	0.0013
ForX (N)	-0.1560	2.1310	2.2966	0.3376	4.1372	0.5714
ForY – weight (N)	0.3708	0.1959	2.1557	0.3514	4.0905	0.5044
ForZ (N)	2.4514	0.5987	1.2538	0.2755	2.1832	0.3778

22 Aug 2012 Data: 20.5-kg weight (201.1 N) used. Not filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0044	0.0075	0.0108	0.0027	0.0198	0.0043
CoPZ vs. MarkerZ (m)	0.0025	0.0160	0.0200	0.0048	0.0376	0.0090
ForX (N)	-0.4519	1.8811	6.9471	0.9606	12.8665	1.7370
ForY – weight (N)	-0.2053	3.3445	8.7349	1.2128	16.6406	2.2069
ForZ (N)	1.9842	0.5414	4.8066	0.5063	8.8543	0.6695

22 Aug 2012 Data: 20.5-kg weight (201.1 N) used. 10 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0044	0.0075	0.0040	-0.00070	0.0071	0.00097
CoPZ vs. MarkerZ (m)	0.0025	0.0160	0.0083	0.0023	0.0154	0.0045
ForX (N)	-0.4456	1.8937	2.9230	0.6668	5.4872	1.1366
ForY – weight (N)	-0.1953	3.3429	3.6227	0.5270	6.7923	0.8205
ForZ (N)	1.9906	0.5417	1.7232	0.1745	3.2258	0.2296

22 August 2012 Data: 20.5-kg weight (201.1 N) used. 6 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0044	0.0075	0.0029	0.00047	0.0051	0.00061
CoPZ vs. MarkerZ (m)	0.0025	0.0160	0.0066	0.0026	0.0114	0.0039
ForX (N)	-0.4469	1.8983	2.1435	0.4804	4.0214	0.8480
ForY – weight (N)	-0.1958	3.3449	2.5308	0.3236	4.7092	0.4686
ForZ (N)	1.9900	0.5428	1.1805	0.1021	2.2398	0.1757

Appendix C: NHRC Force Plate Measurements for Group 2

NHRC CAREN Measurements: 11.4-kg weight filtered at 0, 6, and 10 Hz

21 August 2012 Data: 11.4-kg weight (111.8 N) used. Not filtered. 15 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0080	0.0108	0.0076	0.0018	0.0143	0.0032
CoPZ vs. MarkerZ (m)	0.0027	0.0204	0.0166	0.0036	0.0313	0.0064
ForX (N)	0.1279	3.4645	2.6014	0.2836	4.7625	0.4011
ForY – weight (N)	2.2808	2.5521	4.5397	0.4006	8.5371	0.7680
ForZ (N)	-3.2503	1.7369	1.9935	0.5243	3.6885	1.0604

21 August 2012 Data: 11.4-kg weight (111.8 N) used. 10 Hz filtered. 15 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0080	0.0108	0.0031	0.00060	0.0059	0.0011
CoPZ vs. MarkerZ (m)	0.0027	0.0204	0.0070	0.0015	0.0127	0.0026
ForX (N)	0.1283	3.4628	1.1930	0.3137	2.1289	0.3826
ForY – weight (N)	2.2785	2.5556	1.8993	0.2323	3.6068	0.4615
ForZ (N)	-3.2507	1.7395	0.8705	0.2676	1.5716	0.4358

21 Aug 2012 Data: 11.4-kg weight (111.8 N) used. 6 Hz filtered. 15 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0080	0.0108	0.0022	0.00046	0.0042	0.00072
CoPZ vs. MarkerZ (m)	0.0027	0.0204	0.0050	0.0014	0.0092	0.0022
ForX (N)	0.1293	3.4631	0.8472	0.3934	1.4898	0.4736
ForY – weight (N)	2.2772	2.5547	1.3590	0.1558	2.5478	0.2592
ForZ (N)	-3.2499	1.7404	0.5997	0.2801	1.0338	0.3357

Appendix D: NHRC Force Plate Measurements for Group 1

NHRC CAREN Measurements: 31.9-kg weight filtered at 0, 6, and 10 Hz

13 Aug 2012 Data: 31.9-kg weight (312.9 N) used. Not filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0033	0.0055	0.0125	0.0025	0.0231	0.0048
CoPZ vs. MarkerZ (m)	0.0071	0.0122	0.0251	0.0138	0.0460	0.0258
ForX (N)	-1.7364	2.0397	14.2008	4.6446	25.1141	6.2765
ForY – weight (N)	0.3969	4.4595	15.0415	4.5181	27.3112	8.7957
ForZ (N)	-1.2264	2.0386	8.9855	1.5948	16.6170	3.2974

13 Aug 2012 Data: 31.9-kg weight (312.9 N) used. 10 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.00032	0.0055	0.0044	0.00080	0.0077	0.0013
CoPZ vs. MarkerZ (m)	0.0071	0.0122	0.0085	0.0040	0.0154	0.0060
ForX (N)	-1.7384	2.0325	5.0456	2.0771	8.6158	2.5093
ForY – weight (N)	0.4116	4.4447	5.7554	1.6555	9.8865	2.4810
ForZ (N)	-1.2377	2.0421	3.0830	1.1062	5.2985	1.5502

13 Aug 2012 Data: 31.9-kg weight (312.9 N) used. 6 Hz filtered. 10 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.00032	0.0054	0.0029	0.00057	0.0052	0.00095
CoPZ vs. MarkerZ (m)	0.0071	0.0122	0.0067	0.0032	0.0115	0.0047
ForX (N)	-1.7398	2.0295	3.6100	1.6423	5.9934	2.0000
ForY – weight (N)	0.4191	4.4402	4.3259	1.8091	7.4594	2.4454
ForZ (N)	-1.2400	2.0483	2.2766	1.0909	3.7780	1.2759

Appendix E: NMCSD Force Plate Measurements for Group 5

NMCSD AMTI Force Plate Measurements: 2.5-kg, 11.4-kg, and 20.5-kg weights

27 Aug 2012 Hospital Data: 2.5-kg weight (24.5 N) used. 5 trials. New coordinates XY-plane: plate Z: vertical.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0035	0.0130	0.0057	0.0025	0.0108	0.041
CoPY vs. MarkerY (m)	0.0069	0.0093	0.0044	0.0014	0.0083	0.0028
ForZ – weight (N)	-1.9113	1.4671	0.7772	0.0411	1.4720	0.0928

27 Aug 2012 Hospital Data: 11.4-kg weight (111.8 N) used. 5 trials. New coordinates XY-plane: plate Z: vertical.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	0.0021	0.0021	0.0011	0.00045	0.0021	0.0072
CoPY vs. MarkerY (m)	-0.0029	0.0026	0.0009	0.00037	0.0017	0.00068
ForZ – weight (N)	-3.2342	1.3226	0.7721	0.0850	1.4800	0.1055

27 August 2012 Hospital Data: 20.5-kg weight (201.1 N) used. 5 trials. New coordinates XY-plane: plate Z: vertical.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0021	00026	0.00059	0.00018	0.0011	0.00031
CoPY vs. MarkerY (m)	-0.0024	0.0046	0.00051	0.00014	0.00094	0.00023
ForZ – weight (N)	-6.3552	1.0852	0.8187	0.04256	1.5180	0.0327

Appendix F: WRNMMC Force Plate Measurements for Group 6

WRNMMC CAREN Measurements: 32.6-kg weight filtered at 10 Hz

27 September 2012 Data: 32.6-kg weight (320 N) used. 10 Hz filtered. 19 trials.

	Average Offset	SD	Average Max Error	SD	Average Noise Range	SD
CoPX vs. MarkerX (m)	-0.0119	0.0074	0.0030	0.0011	0.0054	0.0018
CoPZ vs. MarkerZ (m)	-0.0166	0.0082	0.0056	0.0028	0.0097	0.0046
ForX (N)	-0.1407	1.0244	2.2271	2.1269	3.8893	3.4829
ForY – weight (N)	-4.6528	3.2543	2.1444	1.5858	3.8004	2.7642
ForZ (N)	1.1860	0.3850	1.6844	1.4828	2.9545	2.6092

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD MM YY)
29 10 13

2. REPORT TYPE
Technical Report

3. DATES COVERED (from – to)
Aug 2012 – Aug 2013

4. TITLE
Measurement and Analyses of Force Plate Accuracy and Noise for a Computer Assisted Rehabilitation Environment (CAREN)

5a. Contract Number:
5b. Grant Number:
5c. Program Element Number:
5d. Project Number:
5e. Task Number:
5f. Work Unit Number:61030

6. AUTHORS
Anderson, Brian S.; Sessoms, Pinata H.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Commanding Officer
Naval Health Research Center
140 Sylvester Rd
San Diego, CA 92106-3521

8. PERFORMING ORGANIZATION REPORT NUMBER
13-57

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

Commanding Officer
Naval Medical Research Center
503 Robert Grant Ave
Silver Spring, MD 20910-7500

Chief, Bureau of Medicine and Surgery
(MED 00), Navy Dept
2300 E Street NW
Washington, DC 20372-5300

10. SPONSOR/MONITOR'S ACRONYM(S)
BUMED/NMRC

11. SPONSOR/MONITOR'S REPORT NUMBER(s)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Naval Health Research Center (NHRC) in San Diego houses a Computer Assisted Rehabilitation Environment (CAREN) used for rehabilitation and research of the warfighter. The CAREN system, equipped with a Forcelink treadmill and force plates, experiences variable force plate noise that can change between days and with a slight dependence on the weight placed on the device. The noise affects various applications and prevents consistent controls and accurate data recording. In order to understand the effect that noise has on the system and in CAREN applications, various weights were placed on the platform in multiple 3-second-long trials. The resulting force, center of pressure, and marker data were compared across several weights over multiple days. These data were also compared with another CAREN located at Walter Reed National Military Medical Center (WRNMMC) and with standard in-ground AMTI force plates at Naval Medical Center San Diego (NMCSD) to determine if the noise is only a local effect on the NHRC CAREN. It was determined that the NHRC CAREN and the WRNMMC CAREN experience the same amount of noise, which is much higher than the noise experienced by standard in-ground AMTI force plates such as those at NMCSD. It is recommended that all force and center of pressure data used by CAREN applications be first run through a filter before being used in a task, and that using low-force recordings be used cautiously or avoided entirely.

15. SUBJECT TERMS
signal noise, force plate, CAREN, Naval Health Research Center, NHRC, Motek Medical

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	18a. NAME OF RESPONSIBLE PERSON
UNCL	UNCL	UNCL	UNCL	30	Commanding Officer

18b. TELEPHONE NUMBER (INCLUDING AREA CODE)
COMM/DSN: (619) 553-8429

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18